Project Title: Prediction of Summer Leaf Nitrogen Concentration from Early Season Samples to Better Manage Nitrogen Inputs at the Right Time in Walnuts, Prunes, and Pears

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Supporter(s): California Dried Plum Board. California Walnut Board. California Pear Advisory Board. Fruit Growers Laboratory.

CDFA Funding Request Amount: Year 1: $83,397.55 Year 2: $73,254, Year 3: $ 71,817

Other Funding for Related Research not directly funding this proposal:
The Prune research committee has funded a research project focused on nutrient budgeting and tissue sampling in Prune (Brown PI: $20,000), the provided funds are however inadequate to develop a robust early leaf sampling model. The Walnut Research Board and USDA-SCBG (Brown PI: $41,400) Project number 48 is funding the project “Development of a Nutrient Budget Approach and Optimization of Fertilizer Management in Walnuts” – this project will provide valuable research sites and collaborative data for development of early season leaf sampling methods proposed in this current project. California Pear Advisory Board is providing $9,100 for UC Extension Farm Advisor Chuck Ingels to help with leaf analysis in pear. Fruit Growers Lab will provide all analysis free of charge (estimated value of $15,000).

Agreement Manager: Kevin Waterson, Department of Plant Sciences, One Shields Ave., University of California, Davis, CA, 95616, kbwaterson@ucdavis.edu.
B. EXECUTIVE SUMMARY

Problem: Increasing awareness of the environmental impact of excess nitrogen (N) and new N management regulations demand user-friendly tools to help growers make fertilization decisions. Walnuts (227,000 acres), prunes (58,000 acres), and pears (14,000 acres) are important crops in California, with approximately 300,000 acres combined. Each of these crops uses significant amounts of nitrogen to maintain high yields in fully mature orchards. While these crops have high N demands, application of N in excess of need is prevalent. This is, in part due to a lack of tools to correctly monitor tree nitrogen status early in the season.

Leaf nutrient analysis, is the most widely used monitoring tool to track tree nitrogen status. To use this methodology, growers currently collect leaf samples in summer and then send leaves for lab analysis to compare their values against established standard critical values for summer. However, sampling in summer is too late in the season to adjust current season nitrogen management if needed. This problem was evident in almonds when an industry-wide grower survey was conducted in 2007. The results of this survey suggested that leaf nutrient sampling could be very useful for fertilization management, but only if there were ways to collect and interpret leaf analysis results in the spring rather than the late summer as currently practiced.

Precedent: From 2009 to 2012 a successful CDFA-FREP project (“Development of leaf sampling and interpretation methods for Almond and Pistachio”) was conducted and achieved the goal of developing a robust early season sampling protocol for almonds and pistachios under the direction of Doctors Brown, Saa, and Laca at the University of California, Davis. The results of this project were implemented by the almond and pistachio industries in 2013 and so far have contributed significantly to the improvement of nitrogen management in these crops. In addition, implementation of this tool has been adopted by important commercial labs in California (i.e. Fruit Growers Laboratory, Inc.) and has been made available for all private and commercial users free of charge at:


Proposal: Funding is requested here to 1) develop a leaf nitrogen prediction model to better manage nut (walnut) and fruit (prune, and pear) orchards in California, 2) create a user friendly online interface to help growers, extension specialists and consultants to design nutrient plans based on early season leaf samples for walnuts, prunes and pears as well as pistachios and almonds (for which models have already been developed) 3) promote the use of this tool, and an understanding of these models, to better manage nitrogen inputs at the right time in these nut and fruit trees.

California growers of walnuts, prunes and pears are the primary audience that will stand to potentially benefit from this research by improving their yields and N use efficiency. Commercial Analytical labs will also benefit by offering an improved product to their customers. The walnut, prune and pear industry will benefit by improving compliance with current and future N regulations as well as improving the quality of their products. Consumers and the general public will also benefit from an improved supply of healthy fruits and nuts with decreased environmental impacts.

Response to pre-proposal comments by TASC: As suggested we have reduced the number of crops so that costs and time requirements are not excessive. As suggested we will utilize a
commercial laboratory for analyses. To ensure analytical quality we will submit blind verification samples and retain unused sample material if reanalysis is required. All results will be public and made available to all upon request.

C. JUSTIFICATION

Problem: In tree crop production in California, leaf sampling and critical value analysis represents the primary tool for fertilizer decision making (Brown and Uriu, 1996). Leaf nutrient analysis, is the most widely used monitoring tool to track tree nitrogen status. To use this methodology, growers must collect leaf samples in summer and then send leaves for lab analysis to compare their values against established standard critical values for summer. However, a major perceived constraint with current protocols for leaf sampling in fruit trees is that samples are collected too late in the growing season to be of use for current season nutrient management decisions (Abadia et al., 2004; Abadia et al., 2000; El-Jendoubi et al., 2012; El-Jendoubi et al., 2011; Saa et al., 2014). This problem is particularly evident since more of the 80% of N uptake is complete by the time results of a late summer tissue sampling are available to the grower in August (Muhammad et al., 2015; Saa et al., 2014). Late sampling limits the grower’s ability to make in-season fertilizer adjustments and may encourage late-season fertilizer application that is inefficient and can result in groundwater contamination (Neilsen and Neilsen, 2002; Viers et al., 2012).

Summer sampling (July-August in California) has historically been recommended because leaf nutrient concentration has been shown to be more stable at this time than earlier in the season (Al-Khayat, 2004; Cresswell, 1989; Lilleland and Brown, 1941; Robinson, 1993). The rationale for collecting leaf samples in mid-summer is based on the observation that leaf nutrient concentrations change with leaf development and that the daily change in leaf nutrient concentrations is smallest once leaves have reached their full size and weight, which occurs in most deciduous species in mid-summer. Leaf critical values were therefore developed for this timing, while in practice they are not ‘on time’ to orientate nutrient management decisions.

To forecast leaf nitrogen concentration from spring to summer, would require addressing the issue of changing leaf nutrient requirements with leaf development (Lewis et al., 1993). Lau and Wong (1993), and Radrizzani et al. (2011) have proposed that leaf Ca concentration can be used to predict leaf age and to improve interpretation of leaf nutrient concentration in Hevea and Lecaena leucophala. This approach is however compromised by luxury uptake of Ca when there is abundant Ca in the soil or by low uptake of Ca when K and Mg in the soil compete with its uptake. The potentially confounding effects of these minerals was solved by Saa et al. (2014) who observed that the inclusion of Ca, K, and Mg as a marker of leaf age resulted in an ability to predict leaf nitrogen concentration in almonds. Specifically, Saa et al. (2014) detected in almonds that leaf nitrogen concentration in summer can be predicted (r² = 0.9) from the leaf N and B concentration in spring with the sum of positive charge from K, Ca, and Mg.

This proposal seeks to develop nitrogen prediction models for early season sampling of walnuts, prunes, and pears so that tree nitrogen status can be measured early enough in the season to guide current season fertilization strategies. The first 18 months of this project will be used to develop the leaf sampling protocols and models, subsequently funding is requested to integrate the model into an easy-to-use online interface, and to share that model in a systematic way with the agricultural community to promote adoption. The understanding of how farmers adopt new
agricultural technologies is highly complex and depends upon a range of social, cultural, personal, and economic factors as well as the nature of the innovation itself (Pannell et al., 2006). The adoption of novel technologies and practices is often slower than predicted and is often adopted by less of the target population than desired (McRoberts and Franke, 2008). However when technologies are perceived to be simple, low-risk and low investment, their adoption and diffusion are significantly increased (Batz et al., 1999) and can be enhanced by a thoughtful and systematic plan of information diffusion (Vanclay, 2004).

FREP Mission and Research Priorities: The development of tools and approaches that can be used effectively to monitor plant nutrient status and design efficient fertilizer strategies is a crucial first step toward responsible and profitable fertilizer use. This project aims to provide a sound and practical “early-warning” and monitoring tool for growers to optimize N management in fruit orchards. This tool will improve plant tissue sampling protocols to diagnose excessive, sufficient, and deficient nitrogen levels early in the season. Efficient and responsive fertilizer strategies are essential if we are to protect the Californian environment from non-point fertilizer pollution and are an economic imperative as consumers increasingly demand sustainability and responsible production techniques.

Thus, this project addresses the following FREP’s research priorities for this funding cycle:

- Developing integrated nutrient management tools by creating early season nitrogen prediction models.
- Education and Outreach by creating a website optimized for smart phones, an instructional video, workshops, and seminars.
- Developing New Best Management Practices (BMPs) by moving leaf nitrogen sampling from summer to spring.
- Filling Knowledge Gaps for Nitrogen Management in Specific Crops in the San Joaquin Valley by collaborating with an ongoing project in walnuts to improve leaf sampling protocols.

Impact: In the absence of a reliable nutrient monitoring system growers have made fertilization decisions that are not scientifically validated and that often result in over fertilization. Growers have historically applied nitrogen into their orchards without using a monitoring tool to orientate their fertilization plans. This has often resulted in more nitrogen applied than needed (Viers et al., 2012). Thus, the ability to predict tree nitrogen early in the season could reduce nitrogen contamination and save fertilizer costs, while maintaining potential yields.

Long-Term Solutions: This project will provide a robust new online leaf nitrogen prediction model to better management of nut (walnut) and fruit (prune, and pear) orchards in California. Success will be measured by the reliability of new sampling and analytical protocols and subsequent field-testing, by the nature and effectiveness of outreach activities and by the adoption of new practices by the industry. This project has been developed collaboratively with all major stakeholders (growers, consultants, fertilizer companies, farm advisors, industry, regulatory agencies and analytical laboratories), through this and effective dissemination of our results, we expect excellent buy-in and adoption. This project is well supported by the California Dried Plum Board, California Walnut Board, and California Pear Advisory Board.
Related Research: This project will further field application of the research performed in Dr. Brown’s lab at UC-Davis. A FREP project funded in 2008 (project number: 07-0671) “Development of leaf sampling and interpretation methods for Almond and Pistachio” and its extension in 2010 (project number: 10-0015-SA) provides the basis for the work proposed here. This original project resulted in improved plant tissue sampling protocols to diagnose excessive, sufficient, and deficient nitrogen levels and it has allowed for the development of a simple, but accurate nitrogen budget procedure to plan and guide field-by-field nitrogen management decisions in almonds and pistachios. The research has been adopted as the primary leaf sampling methodology by the almond board and is the basis for the Almond Sustainability Program Nitrogen Management practices (https://www.sustainablealmondgrowing.org) and has been widely adopted by Pistachio growers http://fruitsandnuts.ucdavis.edu/Weather_Services/Nitrogen_Prediction_Models_for_Almond_an d_Pistachio/.

The Walnut and Prune industry are currently providing funding for nitrogen management research by Dr. Brown. However, the funds provided by Walnut and Prune in current projects are inadequate to effectively develop a robust industry wide leaf sampling protocol and model for these crops. Specifically, the current walnut and prune funding allows for sampling of only three locations per crop cultivar while the model development conducted successfully in Almond and Pistachio utilized more than 30 orchard/year locations. Moreover, statistical modeling costs and website development are not covered with the current funds. Therefore, the FREP support requested here will greatly extend the data being collected in current projects to at least 30 orchard/year sites and will allow the development of uniform model strategies and coordinated website, tablet and phone applications. Consistency in technology design and implementation is essential for adoption of this new technology.

Contribution to Knowledge Base: We will utilize this information to predict tree nitrogen status early in the season in several important cultivars. This early season prediction will be a new tool that will be widely available for growers and the overall agriculture industry. This project will, therefore, improve the current monitoring strategies to design better nitrogen fertilization plans. This will contribute to ensuring high productivity and good environmental stewardship. Research will emphasize N, but will include analysis of all essential elements commonly applied in California orchards so that additional models can ultimately be developed for other essential elements. The addition of all essential elements allows the use of multivariable statistic methods, and thus improves our ability to predict summer nitrogen values in the selected cultivars.

The main output of this project will be the new models that will help growers utilize early season analysis to define and optimize their fertilization strategies. Presentations of the results of this work at grower workshops, in extension articles and in popular press will contribute to the knowledge base of stakeholders and improve the management of N in tree crops.

Grower Use: The 2008 CDFA funded survey of almond and pistachio growers simultaneously illustrated that growers were uncomfortable with existing nutrient management strategies and were interested in improved sampling and monitoring strategies (Lopus et al., 2010). There are several specific incentives that will contribute to grower adoption of the tool developed in this project:
Pressure from key buyers to ensure that the fruit is being produced in an environmentally responsible manner. With much of the fruit going to Europe where sustainability and eco-friendly production are essential market considerations.

Legislative pressures that are now mandating the development of nitrogen management plans so that N loading to the environment can be reduced.

Reduction of fertilizer costs by better monitoring of tree N status.

Optimization of timely N planning to both allow growers to augment their N applications in response to tree demand or to reduce applications where N contamination is forecasted.

Adoption of this new tool will be facilitated by strong collaboration with Farm Advisors and industry partners, as well as frequent presentations, workshops and the creation of strong, reliable, and easy to use models. Dr. Brown, who makes numerous presentations both locally and internationally each year, will be emphasizing this work heavily with presentations in the academic sector, fruit industry and fertilizer companies.

D. Objectives: This project is designed to achieve the following three objectives:

Objective 1: To develop a leaf nitrogen prediction model using spring collected samples to predict late summer tissue values. This will allow growers to better manage nitrogen in nut (walnuts) and fruit (prunes, pears) orchards in California by sampling 30 representative orchards for each of three species during 2016 and 2017.

Objective 2: To create a user friendly online interface to help growers, extension specialists and consultants design nutrient plans based on early season leaf samples for walnuts, prunes and pears as well as pistachios and almonds (for which models have already been developed).

Objective 3: To promote the use of this tool, and an understanding of these models, to better manage nitrogen inputs at the right time in these nut and fruit trees.

The achievement of these objectives will allow for early season monitoring of N application that will result in improved planning in terms of “right rate and “right time” of N application.

E. Work Plans and Methods

Work Plan

Objective 1/Task 1: To develop a leaf nitrogen prediction model to better manage nut (walnuts) and fruit (prunes, pears) orchards in California by sampling 30 representative orchards per cultivar during 2016.

Task 1.1 Collection of orchard management data (grower’s survey)

Historical yield, current nutrient management, tree age, tree space and expected yield will be noted for each site. This information will be provided by Farm Advisers or property managers at the time of data collection.

Initiate January 2016: Complete March 2016

Task 1.2 Soil, leaf sample collection and tissue analysis
Ninety orchards will be sampled in 2016 and 30 orchards will be sampled in 2017. Leaves from each orchard will be collected in spring and summer of both years to develop the prediction models. The sampling protocol proposed by Saa et al. (2014) will be used to collect one representative sample per orchard. One soil sample per orchard will also be collected. Soil and tissue determination for the major elements (N, P, K, S, Ca, Mg, B, Zn, Fe, Mn, Cu) in all leaf samples will be processed by the Fruit Growers Laboratory, Inc. Spring leaf samples will be collected April-May, soil samples May-June, summer leaf samples July-August. Database construction, data organization and preliminary statistics will commence May and run through November 2016.

*Initiate March 2016: Complete November 2016*

**Task 1.3 Compilation of weather data**

Growing degree from leaf-out to the sampling date in spring for each site by using the integrated model provided in UC Davis Fruit & Nut Research Information website ([http://fruitsandnuts.ucdavis.edu/](http://fruitsandnuts.ucdavis.edu/)). Detailed weather data will be collected from each location using the California Irrigation Management system (CIMIS website). Since not all locations have nearby CIMIS stations we will also utilize data interpolation routines as needed.

*Initiate January 2016: Complete November 2016*

**Task 1.4 Data Management and Statistical Modeling**

Data management and Statistical Modeling will be performed on spring and summer tissue samples, soil data, and weather data using three analytical software programs. JMP program version 11 (SAS Institute Inc., Cary, NC, 1989-2010) will be used for data management. R core program will be used to program the statistical models. Model development will commence once summer samples have been received in September. Sigma Plot program version 12.5, Systat Software, Inc., San Jose California 95110, USA will be used to plot selected outputs.

*Initiate May 2016: Complete March 2018*

**Task 1.5 Model validation and Cross Validation.**

Eighty-one of the 90 orchards sampled in 2016 will be used to develop the statistical models. The remaining 9 orchards will be used to validate the resulting models. In addition, 30 orchards will be sampled in 2017. Orchards sampled in 2017 will serve to perform a cross validation of the selected models. Please see ‘Methods’ section for further details about this task.

*Initiate March 2017: Complete November 2017*

**Objective 2/Task 2:** To create a user friendly online interface to help growers, extension specialists and consultants design nutrient plans based on early season leaf samples for walnuts, prunes and pears as well as pistachios and almonds (for which models have already been developed).

**Task 2.1 Create an online user-friendly N prediction tool**
Create an online user-friendly interface that allows growers, extension specialists and consultants to easily interact with, understand and use the new leaf N models for walnut, prune, pear, as well as the previously developed models for almond and pistachio. This tool will allow users to input their spring leaf N values and see as an output their expected summer leaf N values and how those compare to critical values. Work on this task will commence in 2016 using previous almond and pistachio data as a template.

Initiate May 2016: Complete June 2018

Task 2.2 Integrate N prediction tool with other nutrient management tools and current information

In 2013, Dr. Brown’s lab partnered with SureHarvest to create a full interactive nutrient budget that allowed users to input particular field level data as well as their leaf N values to create comprehensive N plans for their almond orchards (https://www.sustainablealmondgrowing.org). Similarly, the Brown lab is currently conducting a parallel study in walnuts and prunes to better estimate the right rate of N for these cultivars. These tools as well as other current research on N management for important California fruit and nut crops will be incorporated into this site in an engaging, interactive and simple way so that this website may eventually become a “one-stop-shop” for nutrient planning for fruit and nut orchards. The website will be optimized for smart device use and the package will include extensive written instructions as well as an instructional video.

Initiate Jan 2017: Complete December 2018

Task 2.3 Plan for website sustainability and upkeep

Upon completion of the first edition of the website that will include both new and already established leaf N models, as well as additional information and tools (such as the almond N budget tool), Drs. Brown and Saa will continue to stay up to date on current research with field applicable orchard nutrient research to include within the online platform. Costs of upkeep of the website, which will be housed within UC Davis servers, are included in the requested funds and upkeep is guaranteed for a total of 5 years with the intention that ongoing upkeep beyond that period will be included in future research proposals if needed. In addition we will make the underlying code and models available free for public, governmental and commercial adoption with the requirement that any commercial user sign a licensing agreement specifying that the contributions of UC and CDFA will be recognized and that models updates developed by UC will be implemented immediately upon their release.

Initiate July 2018: Complete December 2018

Objective 3/Task 3: To promote the use of this tool, and an understanding of these models, to better manage nitrogen inputs at the right time in these nut and fruit trees.

Task 3.1 Informational Material Creation

Several extension articles will be written for distribution to farm advisors, industry groups and agricultural press such as ‘Western Farm Press’. These articles will summarize the technical
work and results for farmers, PCAs/CCAs, consultants and others that are interested in directly applying the results of this work in the field.

A peer review scientific manuscript will be a contribution to knowledge base in the scientific field. This manuscript will summarize the findings of this project and will serve to develop further research in this area. The target audience of this manuscript will be researchers working in the area of fruit tree production and plant nutrition.

A short instructional video (i.e. 2 minutes long) will be made to explain how to run the prediction models. In addition, this video will be promoted in Dr. Brown’s presentations widely during and after grant completion.

Initiate November 2017: Complete March 2018

Task 3.2 Stakeholder involvement

Involving stakeholders early in the scientific process enhances buy-in in all projects, when stakeholders know what we are planning they tend to be more receptive to the results. This project has been discussed intensively with the Walnut Board Committee, the prune industry and the pear industry who have pledged a significant commitment to this and associated N management projects. We have also worked closely with analytical labs to ensure the developed models have been available for their use. The involvement of these commercial entities will encourage grower recognition and fertilizer industry attention. Moreover, we will continue to work with farm advisors in each sampling region and will keep them informed of our results to share with their grower networks.

Initiate January 2016: Complete December 2018

Task 3.3 Lab workshops

Two lab workshops will be performed from January 2018 to April 2018. These workshops will focus on teaching commercial labs how to implement the models into their spring sampling results. This will help adoption of the developed models by the Ag. industry. Ideally, the majority of the leaf lab analysis will become familiar with the leaf sampling models by spring 2018 and several of them have already adopted these models for use in Almond and Pistachio.

Initiate January 2018: Complete April 2018

Task 3.4 Scientific seminars and conferences

Annually, Dr Brown and Farm Advisors will present this ongoing research and ultimately the outcomes of this project at numerous events. Dr. Brown for example, typically presents 13-15 large audience presentations annually to meetings of the Almond Research Conference, Western Plant Heath Association, Cal-ASA Plant and Soil conferences, Pistachio Conferences, almond industry events, FREP events, regional Almond Meetings (eg SJV Almond Day, Nickels Field Day), Chemical Industry Grower Days ( Actagro, Tesenderlo Kerley, Yara), PCA/CCA events.
The participation of Almond, Pistachio, Walnut, Dried Plum and Pear boards in supporting this research ensures that the research results will reach growers through industry meetings and websites.

Initiate August 2017: Complete December 2018

Methods

Leaves from each orchard will be collected in spring and summer of 2016 following the new sampling protocol developed by Saa et al. (2014). Each sample will be collected and analyzed for nitrogen (through the combustion method (AOAC, 2006), and for phosphorous, potassium, sulphur, calcium, magnesium, boron, zinc, iron, manganese, copper, and chloride through the nitric digestion method (Meyer, 1992). Samples will be sent to a commercial lab (Fruit Growers Laboratory, Inc.) who has generously offered to provide analytical support. To ensure accuracy of analyses we will submit blind duplicate samples and will retain undigested subsamples of all analyses in the event that repeat analyses are required. All data and models developed in this process will remain publically available in perpetuity. The use of a commercial laboratory will increase rapid industry adoption. Data will be used to model and predict leaf nutrient concentration through the season.

The primary inputs needed to develop the predictive models will be the leaf nutrient concentrations of the elements mentioned above, as well as, the growing degree hours recorded in each study area throughout the season. Combinations of nutrient values, their equivalent weight, and nutrient interactions will be tested throughout the study. During model development, sites will be treated as random variables. Leaf nutrient analysis and their ratios (i.e. N/P) will be treated as fixed effects. The best model to predict nitrogen will be selected by starting with all first and second degree nutrient combinations and interactions, and then by only keeping the effects that are statistically significant. Random effects with no significant likelihood test will be removed. Modelling selection will follow the procedures described in the LMERConvenienceFunctions package (Tremblay, 2013) and Pinheiro and Bates (2000) book.

Eighty-one of the 90 orchards sampled in 2016 will be used to develop the statistical models. The remaining 9 orchards will be used to validate the resulting models. This is an internal validation method, which will test model prediction accuracy. In addition, 30 orchards (10 per cultivar) will be sampled in 2017. Half of the orchards sampled in 2017 will be the same orchards as sampled in 2016, while the other half will be orchards that were not sampled before. Orchards sampled in both years will serve to control for model robustness across years in the same site. Orchards sampled only in 2017 will serve to make an outside cross-validation of the models.

Growing degree days will be recorded from leaf-out to the sampling date in spring for each site by using the integrated model provided in Fruit & Nut Research Information website (http://fruitsandnuts.ucdavis.edu/). If site locations are used that are a substantial distance from nearest CIMIS station we will utilize an interpolation routine to improve data integrity. Because the sample orchards will be selected from throughout the central valley of California, variation in the growing degree days at the time of data collection is expected. This variation will be included as a covariance during model development. A representative soil sample per orchard will be collected. Each soil sample will be composed by pooling soil between 2 to 50 inches in an ‘X’
fashion from the sampling zone. Physical and chemical analysis of the soil samples will also be performed by the Fruit Growers Laboratory, Inc. Soil nutrient values will be used as covariates during model development. Soil physical characteristics will be used to better interpret the results. Historical yield, current nutrient management, tree age, tree space and expected yield will be noted for each site. This information will be provided by Farm Advisers or range managers at the time of data collection.

A website platform that is optimized for smart devices will be developed in 2018 in collaboration with the UC Davis, Fruit&Nut Research and Information Center. In addition, two training courses open to all analytical labs will be taught. These lab training courses will help commercial labs to adopt this new tool. Finally, an instructional video to correctly use the nitrogen models will be recorded and made available online.

**Experimental Site:** Thirty sites per cultivar (90 in total) will be sampled in 2016, while 30 orchards (10 per cultivar) will be sampled in 2017. Detailed information from four prune orchards and three walnuts orchards will be available through different collaborative grants.

Orchard selection will be decided with close coordination with UC farm advisors. Overall, fully mature, well managed orchards, following industry standards, and representing the most planted counties of CA will be selected. For walnuts, the selected variety/rootstock combination will be Chandler on Paradox. For prunes, the selected variety/rootstock combination will be Improved French Prune on M29C. For pears, the selected variety/rootstock combination will be Bartlett on Winter Nelis. This decision is based on the fact that each of the chosen combinations accounts for the biggest percentage of acres in CA and they are industry standards. A map of selected pear orchards made by cooperative extensionist Mr. Ingels is presented in Figure 1. Similar maps for walnuts, and prunes will be developed with the collaboration of cooperative extensionists Ms. Pope and Mr. Niederholzer, respectively.

![Figure 1. Selection of northern and southern pear orchards (Bartlett on Winter Nelis) in CA valley. Orchard selection performed by UC Cooperative Extensionist Chuck Ingles.](image)

**F. Project Management, Evaluation, and Outreach**

**Management:** Dr. Patrick Brown will provide overall coordination of all activities, working closely with the responsible Farm Advisor in each county. Dr. Emilio Laca will be responsible for model development. Dr. Sebastian Saa will be hired part-time as a Post-Doctoral scientist at
UC Davis to manage data collection, run exploratory analyses, draft all resulting scientific manuscripts, and to assist Dr. Emilio Laca with model development. He will also coordinate the creation of the interactive website tool and instructional video. M.Sc. Elana Peach-Fine, who specializes in agricultural extension with the College of Agriculture and Environmental Sciences at UC Davis, will manage project outreach. Data collection will be conducted by a junior specialist hired during spring and summer of 2016. In 2017, a part-time grad student will be hired to collect the remaining samples.

Each Farm Advisor will help with orchard selection and assume coordinating responsibility for orchards located in their county.

**Evaluation** of project performance will be conducted on an ongoing basis. Conference calls are scheduled each 4 months among all participants to ensure progress is being maintained. A Gantt chart project map\(^1\) will guide sampling timing, analysis, statistical model development and analysis and program writing and reporting. Annual and semi-annual reports of activities will be submitted to CDFA and to the co-sponsors.

**Outreach** is a critical component of this project and will be actively pursued based on the tasks listed in objective three of this grant.

Written informational materials, such as industry extension articles, articles in agricultural magazines and peer-reviewed scientific manuscripts will be routinely and frequently produced. A website with an interactive N leaf monitoring tool, as well as nutrient management information and project updates will be maintained at the UC Davis Fruit & Nut Research Information website (http://fruitsandnuts.ucdavis.edu/). Multimedia tools, including an instructional video will also make finding and understanding the results of this research highly accessible.

Industry and commodity board involvement, starting with the project-planning phase will help create buy-in and will encourage grower recognition and fertilizer industry attention. Collaborative work with farm advisors as key project stakeholders will also keep them informed and involved in this research. This will allow them to share our work within their grower networks and for us to participate in field days and workshops organized by them. We will conduct two leaf N analysis and modeling workshops, which will focus on teaching commercial labs how to implement the models into their spring sampling results.

Dr. Brown is a prominent figure at numerous meetings, training workshops and industry events and has an excellent reputation for his ability as an educator; these speaking opportunities provide an ideal large audience venue for outreach. Dr. Brown has been an invited speaker at an average of 12-15 fruit and nut industry and government, non-government and profession society related conferences workshops and training sessions in all of the past 15 years. Collaboration in these grants with Walnut Board (Jan each year), Prune Board (February each year), Apple Research Committee (various dates each year) will ensure that this project receives substantial exposure to the industry through annual industry meetings and research presentations and

\(^1\)A Gantt chart project map to monitor progress and success of the project was made to chronologically visualize each task in month and year. However, because of space limitations, the specific gantt figure is not included in this proposal.
reports. Finally, we will present our work at the 9th International Plant Nutrition Colloquium, Denmark 2017 as this colloquium is one of the most prestigious congresses of plant nutrition around the word and we would have the opportunity to reach a broad audience and learn research and extension strategies from experts working in the area of leaf sampling, modeling and nitrogen management worldwide. (NO FUNDS FROM THIS PROJECT WILL BE USED FOR PRESENTATIONS TO ACADEMIC AUDIENCES)

G. Budget Narrative

Personnel Expenses:

PI Salary (Dr. Laca) @ 8.3% effort in the form of direct funding for the duration of the project. Dr. Laca will develop and manage data collection and develop mathematical models in collaboration with Dr. Saa.

PostDoctoral Scientist (Dr. Saa) @ 40% effort for the duration of the project. Dr. Saa will be primarily responsible for developing sampling protocols, establishing project timelines, and collating and curating data and will assist Dr. Laca in model development.

Outreach Manager (M.Sc. Elana Peach-Fine) @ 5% effort for the duration of the project. Ms Fine will be responsible for development of communication materials including internet, verbal and written messages in collaboration with principal investigator.

Junior Specialist @ 25% effort in year 2 and 15% effort in year 3 to conduct all field sampling, labeling, sub-sampling, and delivery of samples to analytical laboratory.

Graduate Research Assistant @ 15% to assist during summers with Dr Laca in modeling activities.

Professional Consultant Expenses: $10,000 is allocated in all years for website development.

Supplies: Annual software license, sample bags, soil sampler, label printer, printer supplies, copying, postage, mini-fridge that can be plugged in the cigarette lighter to keep the samples fresh ($4,000 in year 1 and $3,000 in year 2). In 2018 costs for printing glossy brochures, handouts and publication costs of $10,000 is requested.

Travel: Leaf sampling will be conducted at 90 sites across the state in 2016 and in 30 sites across the state in 2017. Each site will be visited 2-3 times per year, which results in an estimate number of 250 site visits in 2016 and 80 site visits in 2017. Approximately, 5-7 sites per day can be sampled by one person. Therefore, a total of 20 trips are estimated to manage site visits in 2016 and a total of 8 trips are estimated to manage site visits in 2017. Many of the trips will be two-three days duration and an extra person may be involved to assist with data collection (i.e. farm advisors, a person hired by the collaborative grants, or hourly paid students). The proposed budget represents a best estimate of these costs with shared transportation and hotel rooms. In the final year of the project funds have been allocated for travel to extension meetings and presentations including FREP meetings, CAL-ASA, commodity, industry and extension service meetings.
**Professional/Consultant Services:** Fruit Growers Lab, Inc. will perform for no charge, the chemical analysis of leaf samples and the chemical and physical analysis of soil samples at no cost for this project. A total of 345 analyses will be covered by Fruit Growers Lab, (Table 1).

Table 1. Summary of the samples to be collected throughout the duration of the project.

<table>
<thead>
<tr>
<th>Number of Sites</th>
<th>Sample Type</th>
<th># of Samples in 2016</th>
<th># of Samples in 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>Leaf</td>
<td>180</td>
<td>90</td>
</tr>
<tr>
<td>30</td>
<td>Soil</td>
<td>60</td>
<td>15*</td>
</tr>
</tbody>
</table>

*= half of the orchards sampled in 2017 will be the same as the orchards sampled in 2016.

Costs to develop and upkeep of the developed website, which will be housed within UC Davis servers, will be expended in 2016, 2017 and 2018 and will include 5 years of extended maintenance during which time the website will be maintained in a fully functional and professional form at no charge. In addition we will make the underlying code and models available free for public, governmental and commercial adoption with the requirement that any commercial user sign a licensing agreement specifying that the contributions of UC and CDFA will be recognized and that model updates developed by UC will be implemented immediately upon their release.

**Other Funding Sources:** This project has strong industry support. Prune research committee has funded leaf sampling and nutrient budgeting (Brown PI: $20,000). Walnut Research Board and USDA Project number 48; “Development of a Nutrient Budget Approach and Optimization of Fertilizer Management in Walnuts”. Funding from Prune and Walnut Boards provides money to sample 3 orchards for each crop, as well as detailed data about those orchards. Funding requested here from FREP will extend this sampling to an additional 30 orchards for each crop and 30 orchards for pear. Farm advisors/extensionists, Neiderholzer, Pope, Ingels, will be collaborating in all aspects of this project. We will also leverage existing leaf sample records to provide for a multiyear record and to further enhance model performance.